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Pressure Vessels and Piping

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PERFORMANCE OF MOV STEM LUBRICANTS AT ELEVATED TEMPERATURE¹

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ABSTRACT

This paper documents the results of recent tests sponsored by the U. S. Nuclear Regulatory Commission (NRC) and performed by the Idaho National Engineering and Environmental Laboratory (INEEL). These tests address the effectiveness of the lubricant used on the threaded portion of the valve stem, where the stem nut turns on the stem. Recent testing indicates that an elevated temperature environment can lead to significant increases in the friction coefficient at the stem/stem-nut interface. Most valve actuator qualification tests are performed at room temperature. Similarly, in-service tests are run at ambient plant temperatures, usually 70 to 100°F. Since design conditions can lead to valve operating temperatures in the 200 to 300°F range, it is important to know whether a temperature-induced increase in friction at the stem/stem-nut interface will prevent the required operation of critical valves. Lubricant aging is another phenomenon that might have deleterious effects on the thrust output of a valve actuator. Laboratory experience and field experience both indicate that after long periods in elevated temperature environments, the lubricants may lose their lubrication qualities.

The scope of the current test program includes testing of five different lubricants on four different valve stems. Pending completion of the testing, results of the tests conducted using two of the four stems are discussed. The test series included collection of baseline data at room temperature, single step temperature tests where the temperature of the test setup was elevated directly to 250°F, and step testing where the temperature was elevated in steps to 130, 190, and 250°F, then returned to 70°F. All greases tested showed evidence of physical change after elevated temperature tests. Except for one particular lubricant, all of the greases tested showed increased coefficients of friction at elevated temperatures. Numerous other preliminary conclusions are presented. Recommendations for future research in the area of aged valve stem lubricant performance at elevated temperatures are also presented.

INTRODUCTION

During the past several years, the Nuclear Regulatory Commission (NRC) has supported research addressing the performance of motor-operated valves (MOVs) installed in nuclear power plants. This research included tests and analyses to determine the capability of safety-related MOVs to close (or open) when

subjected to the conditions specified in the plants' design documents. For some safety-related MOVs, these design basis conditions include high flow and pressure loads, high temperatures, and degraded voltage.

This paper presents a discussion of recent tests sponsored by the NRC and performed by the Idaho National Engineering and Environmental Laboratory (INEEL) to address the effectiveness of the lubricant used on the threaded portion of the valve stem, where the stem nut turns on the stem. The effectiveness of this lubricant can impact the thrust output of the valve actuator and reduce the margin for ensuring the performance of the MOV. Recent testing indicates that an elevated temperature environment can lead to significant increases in the friction coefficient at the stem/stem-nut interface. Most valve actuator qualification tests are performed at room temperature. Similarly, in-service tests are run at ambient plant temperatures, usually 70 to 100°F. Since design conditions can lead to valve operating temperatures in the 200 to 300°F range, it is important to know whether a temperature-induced increase in friction at the stem/stem-nut interface will prevent the required operation of critical valves.

Lubricant aging is another phenomenon that might have deleterious effects on the thrust output of a valve actuator. Laboratory experience and field experience both indicate that after long periods in elevated temperature environments, the lubricants may become caked and lose their lubrication qualities. Caked lubricants will likely be more viscous, which might prevent the lubricants from flowing into the region between the threads of the valve stem and stem nut and result in higher friction coefficients. This may cause a reduction in the thrust available from a valve actuator, thus resulting in the inability to either open or close the valve when required. Thus, the object of this testing was to begin to quantify the effects that aging may have on the behavior of lubricants commonly used on the stems and stem nuts of motor-operated valves.

BACKGROUND

In rising stem MOVs, the conversion of actuator output torque to a stem thrust load occurs at the stem nut, as shown in Figure 1. The ratio of actuator torque to stem thrust is generally referred to as the stem factor. For a specific valve stem and stem nut, the only variable

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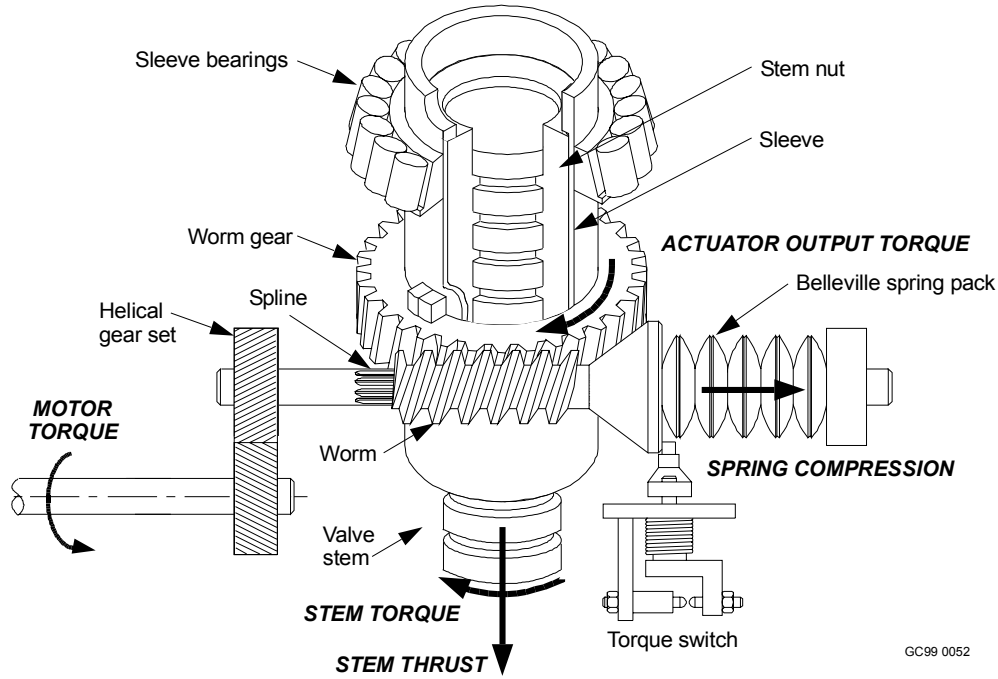


Figure 1. MOV actuator gearbox diagram.

in the conversion of torque to thrust is the coefficient of friction, as shown in the following power screw equation.

$$\frac{T_{\text{output}}}{Th_{\text{stem}}} = \frac{d(0.96815 \tan \alpha + \mu)}{24(0.96815 - \mu \tan \alpha)} = \text{stem factor} \quad (1)$$

where

- T_{output} = The output torque of the valve actuator
- Th_{stem} = The valve stem thrust
- d = $OD_{\text{stem}} - (1/2)\text{Pitch}$
- $\tan \alpha$ = $\text{Lead}/(\pi d)$
- μ = The stem/stem-nut coefficient of friction
- OD_{stem} = The outside diameter of the stem
- Pitch = The distance from the peak of one thread to the peak of an adjacent thread (inches/thread)
- Lead = The distance the stem travels in one revolution of the stem nut (inches/stem revolution)

This equation is written for U.S. Customary units, where torque is in foot-pounds, thrust is in pounds force, and stem diameter and thread pitch and lead are in inches. The pitch is the distance from the peak of one thread to the peak of an adjacent thread (inches/thread). The lead is the distance the stem travels in one revolution of the stem nut (inches/stem revolution). As an example, if the configuration consists of two threads spiraling the stem instead of one, the lead is different from the pitch. (If only one thread spirals the stem, the pitch and the lead are the same.) The output torque consists of the torque delivered to the stem nut. The stem thrust is the thrust applied to the valve stem to move the stem and valve disc. The ratio of torque to thrust, shown in Equation (1), is the stem factor. The term d represents the mean diameter of the stem in terms of the thread contact area, treated as the

midpoint of the depth of the thread. The design of Acme power threads is such that the depth of a single thread is equal to half the pitch. Thus, d is equal to the outside diameter of the stem minus 1/2 the pitch (1/4 the pitch on one side, and 1/4 the pitch on the other side). The term $\tan \alpha$ is the slope of the thread. The term 0.96815 is a constant in the Acme power thread equation, representing the cosine of half the radial thread angle (14.5 degrees for Acme threads). The value 24 (2×12) in the numerator represents the $d/2$ calculation that provides the mean radius of the stem, combined with the conversion from inches to feet; stem measurements are in inches but torque values are in ft-lb.

The mean stem diameter, the thread pitch, and the thread lead for any stem/stem-nut configuration are constants in the power thread equation. The only variable is the coefficient of friction at the interface between the stem and the stem nut.

EARLIER TESTING

Lubricant aging on valve stems has not been extensively tested. One test program was conducted by Atomic Energy of Canada Limited (AECL), who performed tests to evaluate the effects of aging on MOV stem/stem nut lubricants used for MOVs in CANDU and EdF nuclear power plants [1]; however, that work did not consider the effects of different stem/stem nut combinations. A lubricant that is best suited for one type of stem/stem nut configuration may not behave similarly for other stem/stem nut configurations under similar environmental conditions. Also, these tests did not age the lubricant in place on the stem and stem nut. Instead, the lubricant samples were oven aged and then the lubricant was applied to the stem and stem nut to be tested. The operational tests were conducted at 77°F, essentially room temperature.

At the outset of this testing program, baseline tests were performed using an aged lubricant (shelf-aged approximately 10 years)

and an unaged lubricant. Tests were performed at both cold and hot conditions to determine the friction coefficient for these two lubricants using only one stem. The results from these tests showed an unexpected increase in the stem/stem-nut coefficient of friction when the temperature changed from ambient (70°F) to hot (250°F) conditions. This result confirmed the need to investigate the elevated temperature effect on typical lubricants.

CURRENT ELEVATED TEMPERATURE TESTING

The current testing program is designed to indicate whether and higher-than-anticipated coefficients of friction at the stem/stem-nut interface. The elevated temperature testing consists of the following:

- Perform a preliminary investigation, consisting of a series of tests on two stem/stem-nut combinations using five typical lubricants. The purpose of these tests is to evaluate the effect of a temperature increase from ambient (70°F) to design basis (250°F) conditions on friction at the stem/stem-nut interface.
- Perform additional tests to evaluate the sensitivity of the coefficient of friction to increasing operational temperature. The purpose of these tests is to determine if the temperature sensitive performance is dependent on variations in stem thread geometry and to determine the temperature at which performance of each lubricant departs from room temperature baseline data.
- Based on the results from the above testing, perform stem-stem nut lubrication aging tests to determine how the coefficient of friction and the temperature sensitivity might change as the lubricant ages.

Test Design

Test Equipment. The tests were conducted at the INEEL on the motor-operated valve load simulator (MOVLS), shown in Figure 2. The MOVLS is an instrumented test stand that provides dynamometer-type testing of valve actuators using load profiles that are very similar to the load profile a valve actuator would experience when closing a valve against a flow load. The MOVLS was modified for this test program to produce simulated valve strokes with essentially no variation in the stem thrust profile between strokes (see Figure 3) and over the duration of the testing. This was accomplished by adding a sight glass to the MOVLS accumulator to precisely control the water level at the start of each stroke. The initial pressure in the accumulator was controlled using a pressure gage. The volume of water in the accumulator and the overpressure at the beginning of the stroke determine the load profile during the stroke. With multiple strokes all beginning with the same overpressure and water level in the accumulator, the thrust-versus-position profiles will all be essentially the same.

For elevated temperature, the valve actuator was wrapped in heat tape and insulated so as to control the actuator, valve stem threads, and stem nut at the temperature required for testing of the stem nut lubricant. The design configuration allowed operation of the valve actuator without disturbing the heater or insulation.

The following is a list of the major equipment used in the performance of this research.



Figure 2. INEEL Motor Operated Valve Load Simulator (MOVLS).

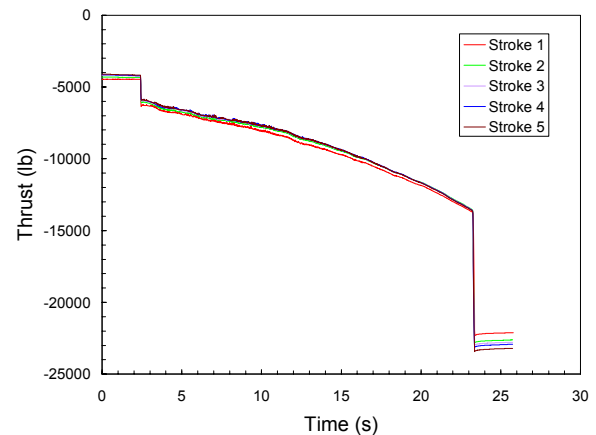


Figure 3. The cold loaded tests show essentially no variation in stem thrust between strokes.

- Limitorque SMB-0 actuator equipped with a Reliance 25 ft-lb 480V ac motor
- Limitorque SMB-1 actuator equipped with a Reliance 60 ft-lb 480 V ac motor
- Stem 2, 1.750-inch-diameter, 1/4-pitch, 1/4-lead valve stem and stem nut made from ASTM A479, 410 stainless steel
- Stem 3, 1.250-inch-diameter, 1/4-pitch, 1/2-lead valve stem and stem nut made from A182, F6 stainless steel

- Stem 4, 2.0-inch-diameter, 1/3-pitch, 3/3 lead valve stem and stem nut made from A314, 410T stainless steel
- Stem 5, 2.125-inch-diameter, 1/4-pitch, 1/2-lead valve stem and stem nut made from A473, Type 416 stainless steel.

The valve stem designations above are those used in previous INEEL testing [2]. Stem 2 is a single-lead stem that exhibited a running coefficient of friction of 0.12. Stem 3 is a double-lead stem that exhibited a running coefficient of friction of 0.1. The rotational speed of the stem nut on Stem 3 is about half that of Stem 2. Stem 4 is a triple-lead stem. During the previous INEEL research program, it averaged a 0.11 running coefficient of friction. Stem 5 is a double-lead stem. During the previous INEEL research program, it averaged a 0.10 running coefficient of friction. All the testing performed under the previous INEEL research program referred to above was accomplished at room temperature using a single lubricant typical of those in common use throughout the nuclear power industry.

This selection of valve stems is intended to allow the current research to examine elevated temperature effects using several different lead designs, running coefficients of friction, end-of-stroke friction behaviors, and stem nut rotational speeds.

Instrumentation. During the testing of each stem/stem-nut combination, the temperature of the MOVLS components were monitored using an array of eight thermocouples strategically placed to allow monitoring of temperatures at various locations throughout the MOVLS. A chart recorder was used to track selected temperature measurements throughout the test period. Full measurement scans using the automated data acquisition system (ADAS) were recorded during the tests.

Additional instrumentation was also utilized to provide a complete array of valve actuator data during the tests. Electrical measurements for the ac motors included the ac line current and voltage for each phase. Motor output torque and speed were measured using a torque cell and tachometer mounted between the motor and the gearbox. A torque arm attached to the valve stem measured the output torque of the gearbox, and an in-line load cell measured valve stem thrust. Other measurements included actuator torque switch trip, torque spring thrust and deflection, and valve stem position. Calibration of the load cells allows a measurement error of 0.6% of full scale. Full-scale capacity of the load cells is 20,000 lb. Calibration of the torque arm allows a measurement error of ± 4 ft-lb.

Test Matrix. The scope of the testing requires several different tests to be run. These tests and the conditions for which the data were used are described in the following paragraphs. The current test program includes testing with five lubricants and the four stem/stem-nut combinations previously described. This results in a total of twenty sets of tests. Thus far, two of the four stem/stem-nut combinations have been tested. Five lubricants commonly used in nuclear power plant MOVs were selected for testing: Exxon Nebula EP1, Chevron SRI, Mobil Mobilgrease 28 (commonly called "Mobil 28"), SWEPCO Moly 101, and Loctite N-5000 Anti-Seize.

Prior to each series of tests, the valve stem and stem nut were removed from the MOVLS and cleaned using a multi-step procedure to remove all traces of the prior lubricant. A fresh application of the next lubricant to be tested was then applied and the stem and stem nut were reassembled into the MOVLS.

The baseline tests provided data from MOVLS setup strokes and test strokes with the lubricant at ambient temperature. No-load/low-

load baseline tests are intended to represent typical in-service tests conducted in the power plants. Data from these tests were used to determine the stability of the stem/stem-nut coefficient of friction at these load levels and to establish the ambient temperature baseline values.

For the high-load baseline tests, the actuator torque switch was set to produce a final stem force near the maximum allowed for the valve stem or the actuator, whichever was lower. The level and pressure in the MOVLS accumulator was determined during the initial setup so that the running load was sufficient to produce a stem thread pressure that exceeded 10,000 psi by the end of the stroke. As described in Reference 2, a stem thread pressure threshold of 10,000 psi is needed for the friction coefficient to stabilize. Stem thread pressure is determined using the measured thrust and an approximate thread area based on one stem thread revolution.

Two groups of elevated temperature tests were performed. In the first group of tests, data at elevated temperature conditions (250°F) were collected for comparison with the baseline data.

The second group of elevated temperature tests was performed to investigate the temperature sensitivity of each lubricant by roughly identifying the temperature threshold at which the coefficient of friction departs from the baseline. This report refers to that temperature threshold as the coefficient of friction departure point. This second group of tests was conducted by raising the valve actuator temperature in steps and performing five loaded strokes to acquire data at each step. Note that the data from each set of five strokes at a given temperature was processed while heat-up began for the next test temperature. The baseline tests described above provided data at ambient temperature ($\sim 70^\circ\text{F}$). The elevated temperature tests described here collected data at three temperature steps: 130, 190, and 250°F. Following the 250°F tests, the actuator was allowed to cool down, and a final test set of tests was performed at ambient temperature (70°F).

Table 1 summarizes the test sequence. The sequence listed in Table 1 has been performed on two of the four stems, with all five lubricants, for a total of ten sets of tests. Testing with the other two stems is proceeding.

RESULTS

As mentioned earlier, the complete test series is still in progress. Thus, the following discussion of results is preliminary and is necessarily limited to the data collected from the completed tests.

The purpose of the elevated temperature tests is to evaluate the change in stem/stem-nut coefficient of friction as conditions change from normal in-plant temperatures to design-basis temperatures. The test series consisted of two strategies:

- Single-step design-basis tests, where the temperature was taken from 70°F directly to 250°F and then back to 70°F
- Temperature step tests, where the temperature was increased from 70°F in three steps, typically 130, 190, and 250°F, then returned to 70°F at the conclusion of testing.

To date, five typical lubricants have been tested on two stem/stem-nut configurations, Stem 2 and Stem 3 (driven by the SMB-0 actuator). The same five lubricants are being tested on Stem 4 and Stem 5 (driven by the SMB-1 actuator). Results from the Stem 4 and Stem 5 tests will be discussed in a subsequent paper.

Table 1. Test sequence.

Test Type	Description
Elevated Temperature Tests	
Setup	Various loads, ambient temperature (multiple strokes)
Baseline (Heatup)	High load, ambient temperature (five strokes)
Hot tests (Cooldown)	High load, elevated temperature at 250°F (five strokes)
Final	High load, ambient temperature (five strokes)
Temperature Step Tests	
Baseline (Heatup)	High load, ambient temperature (five strokes)
Step 1 (Heatup)	High load, elevated temperature at 130°F (five strokes)
Step 2 (Heatup)	High load, elevated temperature at 190°F (five strokes)
Step 3 (Cooldown)	High load, elevated temperature at 250°F (five strokes)
Final	High load, ambient temperature (five strokes)

It is very important to understand how performance characteristics might change due to periodic valve cycling, changes from static to design basis conditions, and valve and lubricant aging. It is important to know if performance characteristics measured during a test can be considered typical of subsequent MOV performance, specifically design basis operation. Measured values for stem/stem-nut coefficient of friction are key factors in setting torque switches to appropriate levels. Increases in this value decrease the thrust available to overcome design basis loads, while decreases in this value increase final thrust, with the possibility of overloading valve and actuator structural components.

Our evaluation of each lubricant was divided into three topics.

- Physical observations
- Consistency in performance among strokes
- Change with temperature

The following discussion addresses each of these topics. The discussion addresses both stem/stem-nut combinations tested.

The reader should note that a large amount of data was obtained in the course of performing these tests. Results for two of the four stems are summarized in Table 2 and further discussed in the paragraphs below; however, of necessity, only selected examples of the data plots and pictures used to document the results are contained in this paper due to space constraints. An interim report [3] containing the complete body of data plots is available through the NRC. The complete body of data and pictures documenting the tests for all four valve stems will be published in a final report at the completion of the testing program.

Physical Observations

The method used to lubricate the stems prior to testing was identical for all greases tested. A thick layer of the grease was

applied to the stem and the stem nut was then rotated about the stem by hand to produce a thin uniform layer. A small bead of lubricant was allowed to remain on each end of the stem nut to ensure adequate supply was present to allow the stem to re-lubricate itself during valve strokes. This is consistent with typical industry practices for stem lubrication. After the testing was completed, the stem and stem nut were removed and the lubricant was inspected.

Post-test examination showed that three of the greases changed color during the elevated temperature testing. Figure 4 shows Stem 2 with a fresh coat of the Mobil 28 grease prior to testing whereas Figure 5 is a photograph of the stem and lubricant after elevated temperature testing. Color photographs show that the lubricant changed from bright red to almost black.

Since the SWEPCO Moly 101 is nearly black in its initial state, color change could not be detected. The Loctite N-5000 Anti-Seize separated into silver-colored and clear components and flowed down the stem during elevated temperature testing. The separated N-5000 lubricant is shown in Figure 6.

Post-test examinations conducted after the test assembly had cooled to room temperature indicated that all the greases had thickened. In the case of the N-5000, it is apparent from Figure 6 that the lubricant became sufficiently fluid to separate and flow down the stem at elevated temperature conditions. However, after cooldown even the separated components were noticeably thicker than the original lubricant. Smear comparisons were also made with each lubricant. These qualitative comparisons consisted of applying to a clean sheet of paper a smear of new, unused lubricant and a smear of the same lubricant removed from the valve stem after elevated temperature testing. Observations were then made regarding the color, viscosity, and base oil retention of the lubricants. Besides the color and viscosity changes noted above, it was observed that the oil

Table 2. Summary of lubricant test results for two stems.

Observation Topic	Exxon Nebula EP1	Chevron SRI	Mobil Mobilgrease 28	SWEPCO Moly 101	Loctite N-5000 Anti Seize
Physical observations					
Stem 2	Color darkened (from tan to brown). Grease thickened during hot tests.	Color darkened (from green to brown). Grease thickened during hot tests.	Color darkened (from red to nearly black). Grease thickened during hot tests. Possible loss of some base oil.	Could not detect color change due to nearly black normal color. Grease thickened during hot tests.	Grease separated into silver-colored and clear components. Grease ran down valve stem during elevated temperature tests.
Stem 3	Color darkened (from tan to brown). Grease thickened during hot tests.	Color darkened (from green to brown). Grease thickened during hot tests.	Color darkened (from red to nearly black). Grease thickened during hot tests. Possible loss of some base oil.	Could not detect color change due to nearly black normal color. Grease thickened during hot tests.	Grease separated into silver-colored and clear components. Grease ran down valve stem during elevated temperature tests.
Consistency among test strokes					
Stem 2	Lower friction on first cold stroke. Consistent friction on hot strokes. Increased scatter at higher temperature.	Good repeatability on cold strokes. Increasing friction variability on hot strokes.	Wide spread between results at all temperature levels.	Wide variation among strokes at elevated temperatures (coefficient of friction values as high as .20).	Unpredictable first stroke coefficient friction values. Wide spread between results at all temperature levels.
Stem 3	Lower friction on first cold stroke. Consistent friction on hot strokes. No scatter at higher temperature.	Improved repeatability on cold strokes. Less friction variability on hot strokes than Stem 2.	Less variability between strokes than seen on Stem 2 - all temperature levels. First stroke had lower friction than subsequent strokes on hot tests.	Almost no variation between strokes for all temperatures.	Unpredictable first stroke coefficient friction values. Consistent results at elevated temperatures. Coefficient of friction did not return to cold baseline values after hot tests.
Changes with temperature					
Stem 2	No significant change in friction coefficient.	Large increase in friction (25%) with increased temperature.	28% increase in friction coefficient.	37% increase in friction coefficient.	29% increase in friction coefficient.
Stem 3	No significant change in friction coefficient.	Large increase in friction (20%) with increased temperature.	18% increase in friction coefficient. Later tests showed no sensitivity to increasing temperature.	13% increase in friction coefficient.	Large variations. 40% increase in friction coefficient for first strokes.

content appeared to remain consistent through the heatup and cooldown except for the separated N-5000 and the Mobil 28. Figure 7 shows the Mobil 28 smear comparison two days after the samples were applied to the paper. In Figure 7 it can be seen that the radius of

absorption into the paper for the tested sample was reduced to about half that of the unused sample. It was also noted that the color had changed.

Consistency Among Strokes

The test data show variations in consistency between strokes for the different greases used.

Exxon Nebula EP1 performance included a lower friction value on the first room temperature stroke followed by fairly consistent friction values for the remaining “cold” strokes. Figure 8 shows a plot of the room temperature test data for EP1 on Stem 2. Increasing data scatter was observed for the 250°F test strokes. These data are shown in Figure 9.



Figure 4. Mobil 28 lubricant applied to Stem 2 prior to testing.

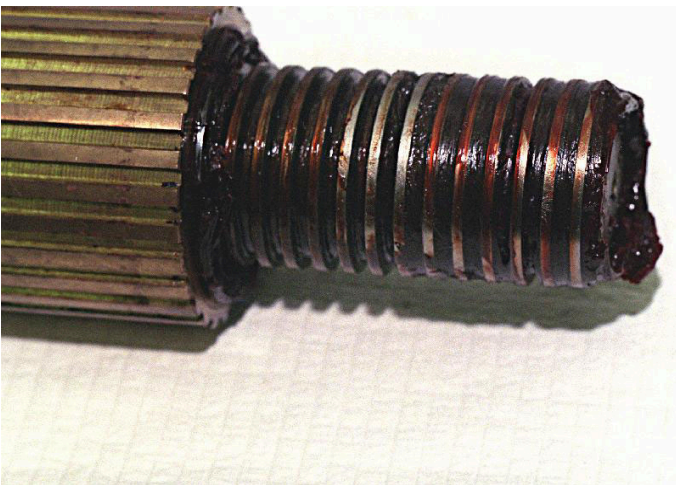


Figure 5. Mobil 28 lubricant on Stem 2 after elevated temperature tests.



Figure 6. N-5000 lubricant separated during elevated temperature testing.

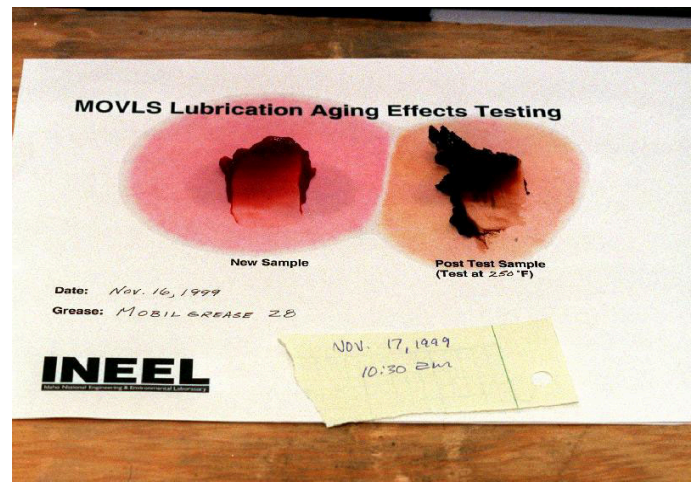


Figure 7. Smear comparison of Mobil 28 two days after application to paper.

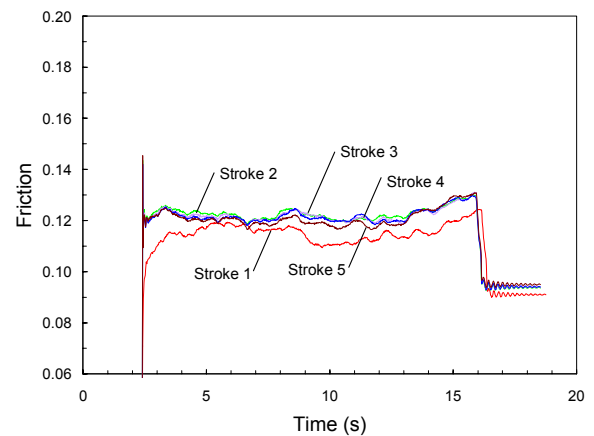


Figure 8. A lower friction value was recorded for the first test stroke at room temperature using Exxon Nebula EP1.

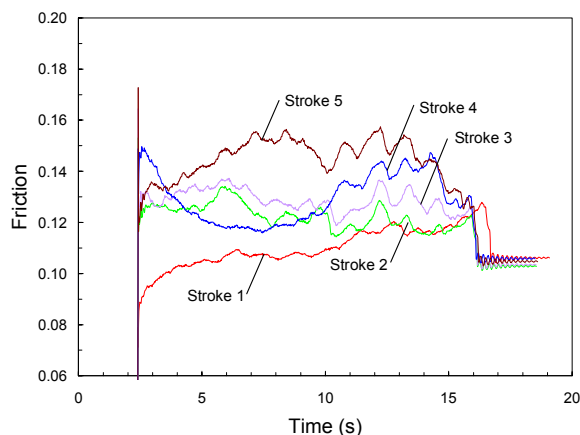


Figure 9. Elevated temperature testing (250°F) of Exxon Nebula EP1 produced increased data scatter.

The tests run with Chevron SRI grease on Stem 2 and Stem 3 showed good repeatability among the five strokes. As the temperatures increased, the test results with Stem 2 showed some increase in variability. When Stem 3 was tested with Chevron SRI, similar results to the Stem 2 characteristics were observed, but with tighter repeatability among strokes at cold baseline and in all the elevated temperature tests. Figure 10 shows the repeatability of the test strokes for Stem 3 at 250°F.

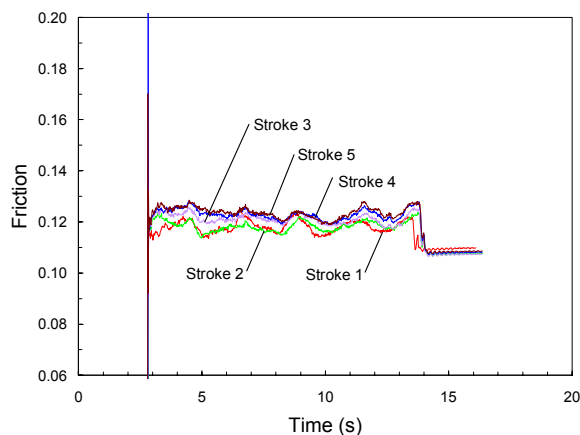


Figure 10. Repeatability of test strokes using Stem 3 with Chevron SRI at 250°F.

Mobil 28 and SWEPCO Moly 101 provided similar behavior in regard to consistency between strokes. Stem 2 test results with each of these lubricants showed significant variations in the friction signatures. This behavior continued as temperature was increased. When Stem 3 was tested with each of these two lubricants, much less variability between strokes was observed at all temperatures. However, with Mobil 28 applied to Stem 3 we did observe that at elevated temperatures, the friction on the first stroke was much lower whereas the succeeding stroke friction values were tightly grouped. Figure 11 uses Mobil 28 on stem 2 to demonstrate the friction value variability

discussed above. Figure 12 uses Mobil 28 to demonstrate the typical good repeatability observed for both Mobil 28 and Moly 101 tested with Stem 3 and also demonstrates the low first stroke friction value observed with Mobil 28 at elevated temperature.

The Loctite N-5000 Anti-Seize lubricant produced wide variations in friction values among the test strokes at all temperature values when tested with Stem 2. Also, the test strokes with this lubricant produced very unpredictable first stroke friction values for both Stem 2 and Stem 3 at all temperatures. Consistency of the friction values among the test strokes improved during the elevated temperature tests using Stem 3; however, the unpredictable first stroke phenomenon persisted. Figure 13 presents an example of both the unpredictable first stroke results and the wide variability in results observed with the N-5000 lubricant discussed above.

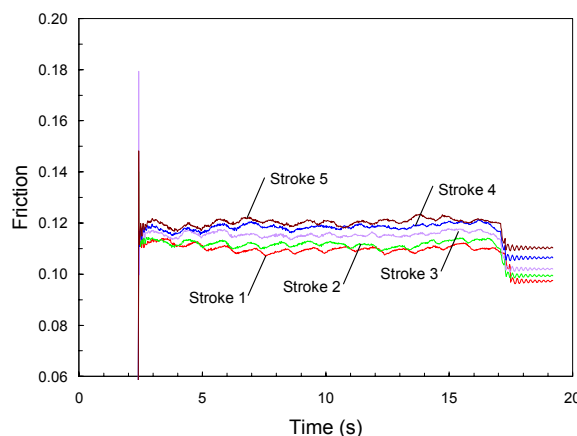


Figure 11. Mobil 28 tested with Stem 2 demonstrates variability of friction values.

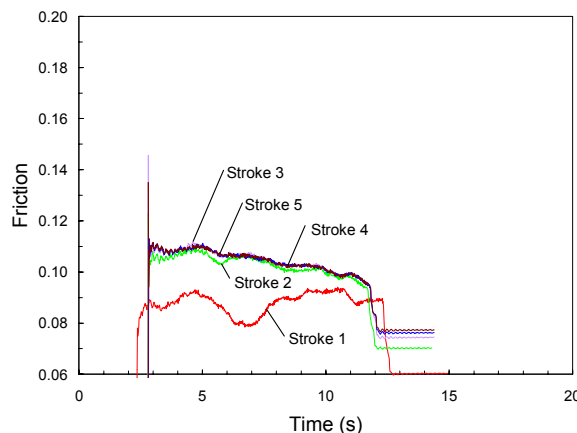


Figure 12. Mobil 28 tested on Stem 3 is a typical example of the good repeatability in friction observed with Mobil 28 and Moly 101 tests on stem 3.

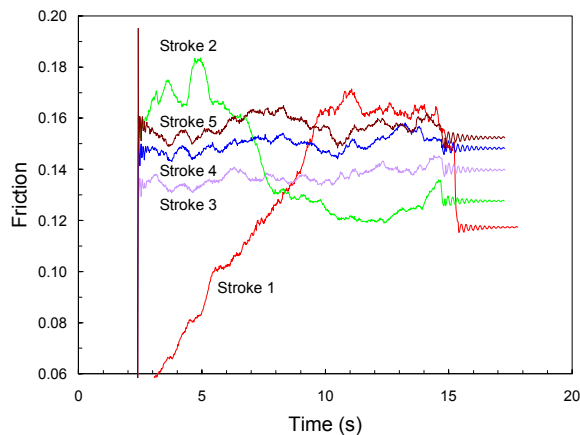


Figure 13. Typical example of the unpredictable first stroke friction results and variability for Loctite N-5000 Anti-Seize.

Changes With Temperature

Except for the Exxon Nebula EP1, the elevated temperature tests yielded increases in friction with increased temperature.

The test strokes with both Stem 2 and Stem 3 lubricated with Exxon Nebula EP1 demonstrated essentially no change due to elevated temperature. This is in contrast to the elevated temperature test results for the other four lubricants. At elevated temperatures, the friction values yielded increases ranging from 25% up to 37% for the Stem 2 tests. For Stem 3 the friction increases ranged from 13% to 40% during the elevated temperature tests using Chevron SRI, Mobil 28, Moly 101, and N-5000 Anti-Seize.

The average friction value of each group of five test strokes at each temperature was determined. The averages were then plotted to provide a graphical representation of the changes in friction with increasing temperature. Figure 14 shows the minimal temperature effect that was observed for the Nebula EP1 lubricant. Figure 15 demonstrates a 21% increase for the single step test using Stem 3 lubricated with Chevron SRI and Figure 16 demonstrates the 37% increase that was observed in the multi-step test with Stem 2 lubricated with Moly 101.

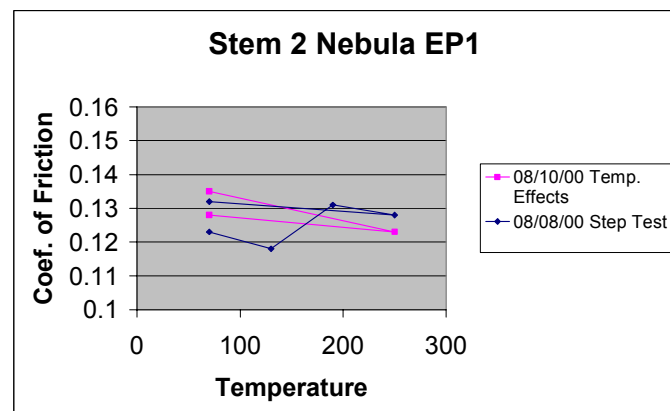


Figure 14. Minimal temperature effect on friction values was observed with Nebula EP1 lubricant.

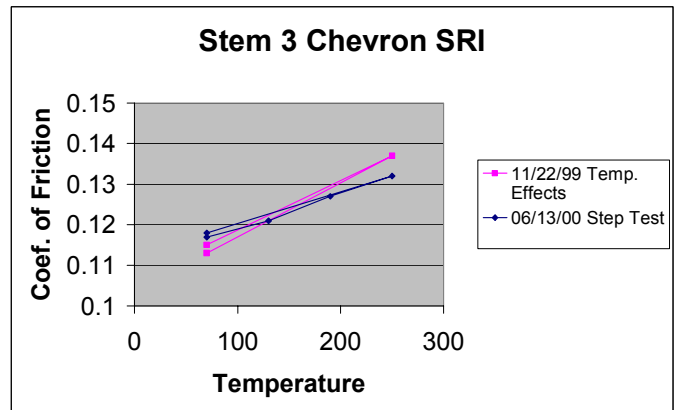


Figure 15. A 21% increase in friction was observed on the single-step elevated temperature test using Stem 3 and Chevron SRI.

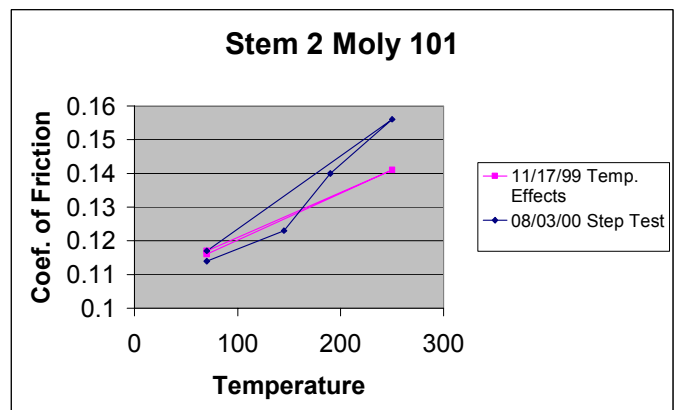


Figure 16. A 37% increase in friction was observed in the multi-step elevated temperature test using Stem 2 and Moly 101.

CONCLUSIONS

This paper describes the interim results in the ongoing efforts to evaluate the effects of elevated temperature on the performance of the lubricants used in typical stem/stem nut configurations found on MOVs in nuclear power plants. The following preliminary conclusions are based on the work completed to date:

- All greases tested showed evidence of physical change after elevated temperature tests. EP1, SRI, and M28 changed color. Because new Moly 101 is nearly black in color, physical changes indicated by color were harder to detect. Color change in this lubricant was not detectable. N-5000 separated into silver-colored and clear components. All of the lubricants thickened during elevated temperature testing.
- Consistency among test strokes was highly dependent upon the lubricant and stem-stem nut combination. This is readily demonstrated by the data contained in Table 2. For example, consistent stroke-to-stroke coefficient of friction values were obtained when testing Exxon Nebula EP1 with Stem 2 at elevated temperatures; however, when SWEPCO Moly 101 was tested on

this same stem, wide variations were observed in the stroke-to-stroke coefficient of friction values.

- Except for the case of Exxon Nebula EP1, increases in the coefficient of friction were observed at elevated temperatures for all lubricants tested. No significant differences in the coefficient of friction were observed between the cold tests and the elevated temperature tests for Exxon Nebula EP1. However, increases ranging from 13% (Moly 101 on Stem 3) to 40% (Loctite N-5000 on Stem 3) were observed for the other lubricant and stem-stem nut configurations.

RECOMMENDATIONS FOR FUTURE RESEARCH

The results of the testing completed to date indicate several areas of recommended continuing research activities. The following paragraphs briefly describe these research topics. Note that the research topics listed below are not listed in any particular order of priority.

Test Additional Stem/stem Nut Combinations

Present research results indicate that friction coefficients vary with temperature and are also influenced by the stem's thread configuration. Testing of additional stem/stem nut sizes and thread configurations will provide possible insights on the general applicability of the test results to combinations of lubricants and stem/stem nut configurations. This information might then demonstrate the applicability of the results to broader groups of stem sizes versus the necessity to perform individual tests for each specific combination of lubricant and stem/stem nut to determine acceptable values of the coefficient of friction.

Conduct Further Research To Characterize Lubricant Aging Mechanisms

Limited discussions have been held to date with the manufacturers regarding the performance of their products as a valve stem lubricant. The lubricant manufacturers generally orient their test programs to assess performance in bearings or other applications where the lubricant will be "worked" or mixed during service. No information seemed to be readily available regarding aging mechanisms applicable to nuclear plant conditions where the lubricant may sit idle on a valve stem for extended periods between strokes. Additional discussions with the manufacturers may provide additional information. Chemical analysis of new grease compared to aged grease to characterize aging mechanisms and processes affecting changes in grease properties would be another valuable approach to obtaining this information.

Conduct Additional Tests Using Different Stem Pressures.

The testing accomplished to date has been conducted with the MOVLS configured to provide thread pressure of approximately 10,000 psi during the stroke. Additional testing performed using different thread pressures would provide insights about the sensitivity of the lubricants to this variable when tested at elevated temperatures.

Conduct Further Testing And Evaluation Regarding Data Scatter.

Certain lubricants tested exhibited wide scatter in the friction coefficient results. Additional tests with these lubricants applied to the same stems would provide additional data that would indicate the consistency of this phenomenon.

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